

(12) **United States Patent**  
U-yen et al.

(10) **Patent No.:** **US 9,383,254 B1**  
(45) **Date of Patent:** **Jul. 5, 2016**

(54) **SYMMETRIC ABSORBER-COUPLED  
FAR-INFRARED MICROWAVE KINETIC  
INDUCTANCE DETECTOR**

(58) **Field of Classification Search**  
CPC ..... G01J 5/02; G01J 5/08; H01Q 1/38  
See application file for complete search history.

(71) Applicant: **The United States of America as  
represented by the Administrator of  
the National Aeronautics and Space  
Administration**, Washington, DC (US)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,310,346 B1 \* 10/2001 Boreman ..... G01J 5/08  
250/338.1

(72) Inventors: **Kongpop U-yen**, Arlington, VA (US);  
**Edward J. Wollack**, Clarksville, MD  
(US); **Ari D. Brown**, Baltimore, MD  
(US); **Thomas R. Stevenson**, Rockville,  
MD (US); **Amil A. Patel**, Palo Alto, CA  
(US)

OTHER PUBLICATIONS

P.K. Day, "Antenna-coupled microwave kinetic inductance detectors," Jan. 4, 2006, Nuclear Instruments and Methods in Physics Research A 559 (2006), pp. 561-563.\*

\* cited by examiner

(73) Assignee: **The United States of America as  
represented by the Administrator of  
the National Aeronautics and Space  
Administration**, Washington, DC (US)

*Primary Examiner* — David Porta  
*Assistant Examiner* — Faye Boosalis

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 0 days.

(57) **ABSTRACT**

The present invention relates to a symmetric absorber-coupled far-infrared microwave kinetic inductance detector including: a membrane having an absorber disposed thereon in a symmetric cross bar pattern; and a microstrip including a plurality of conductor microstrip lines disposed along all edges of the membrane, and separated from a ground plane by the membrane. The conducting microstrip lines are made from niobium, and the pattern is made from a superconducting material with a transition temperature below niobium, including one of aluminum, titanium nitride, or molybdenum nitride. The pattern is disposed on both a top and a bottom of the membrane, and creates a parallel-plate coupled transmission line on the membrane that acts as a half-wavelength resonator at readout frequencies. The parallel-plate coupled transmission line and the conductor microstrip lines form a stepped impedance resonator. The pattern provides identical power absorption for both horizontal and vertical polarization signals.

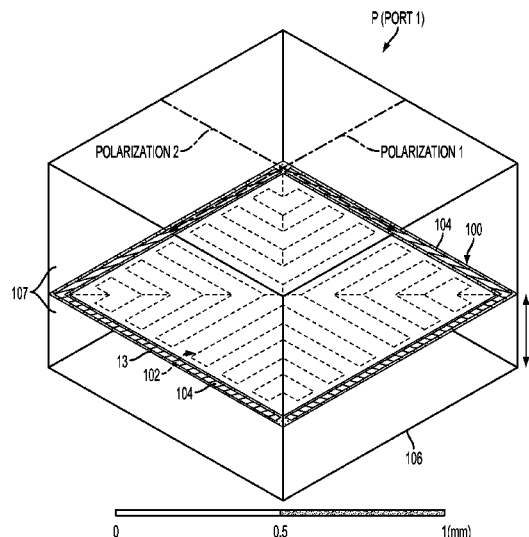
(21) Appl. No.: **14/497,238**

(22) Filed: **Sep. 25, 2014**

(51) **Int. Cl.**  
**G01J 5/02** (2006.01)  
**G01J 5/08** (2006.01)  
**H01Q 1/38** (2006.01)  
**G01J 1/42** (2006.01)  
**H01P 7/08** (2006.01)  
**H01L 39/10** (2006.01)

(52) **U.S. Cl.**  
CPC . **G01J 1/42** (2013.01); **H01L 39/10** (2013.01);  
**H01P 7/082** (2013.01)

**16 Claims, 6 Drawing Sheets**



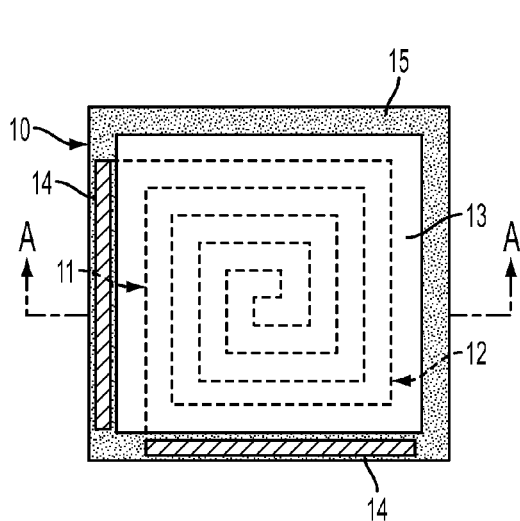


FIG. 1  
PRIOR ART

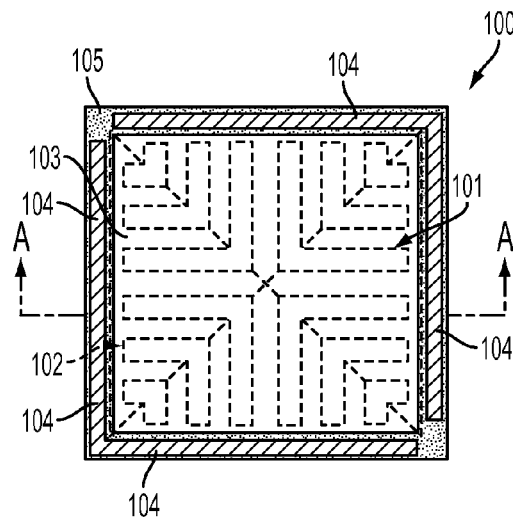


FIG. 3

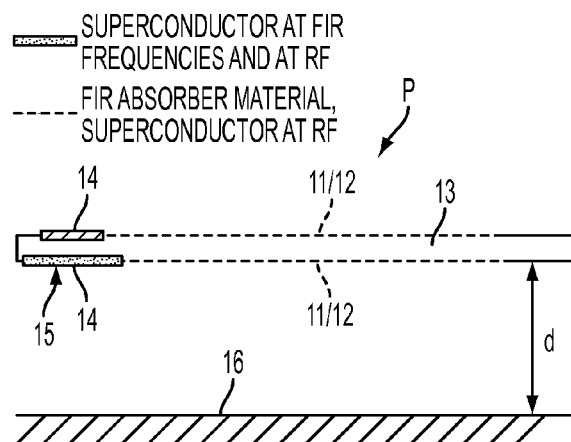


FIG. 2  
PRIOR ART

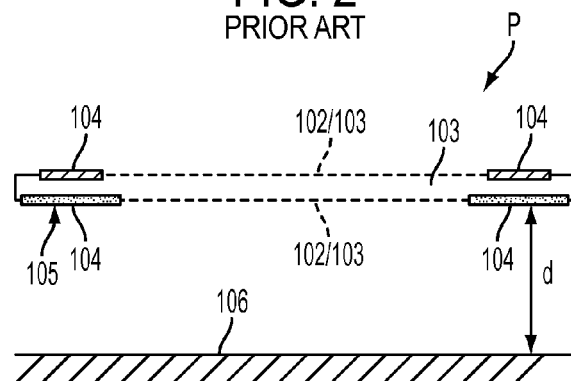


FIG. 4

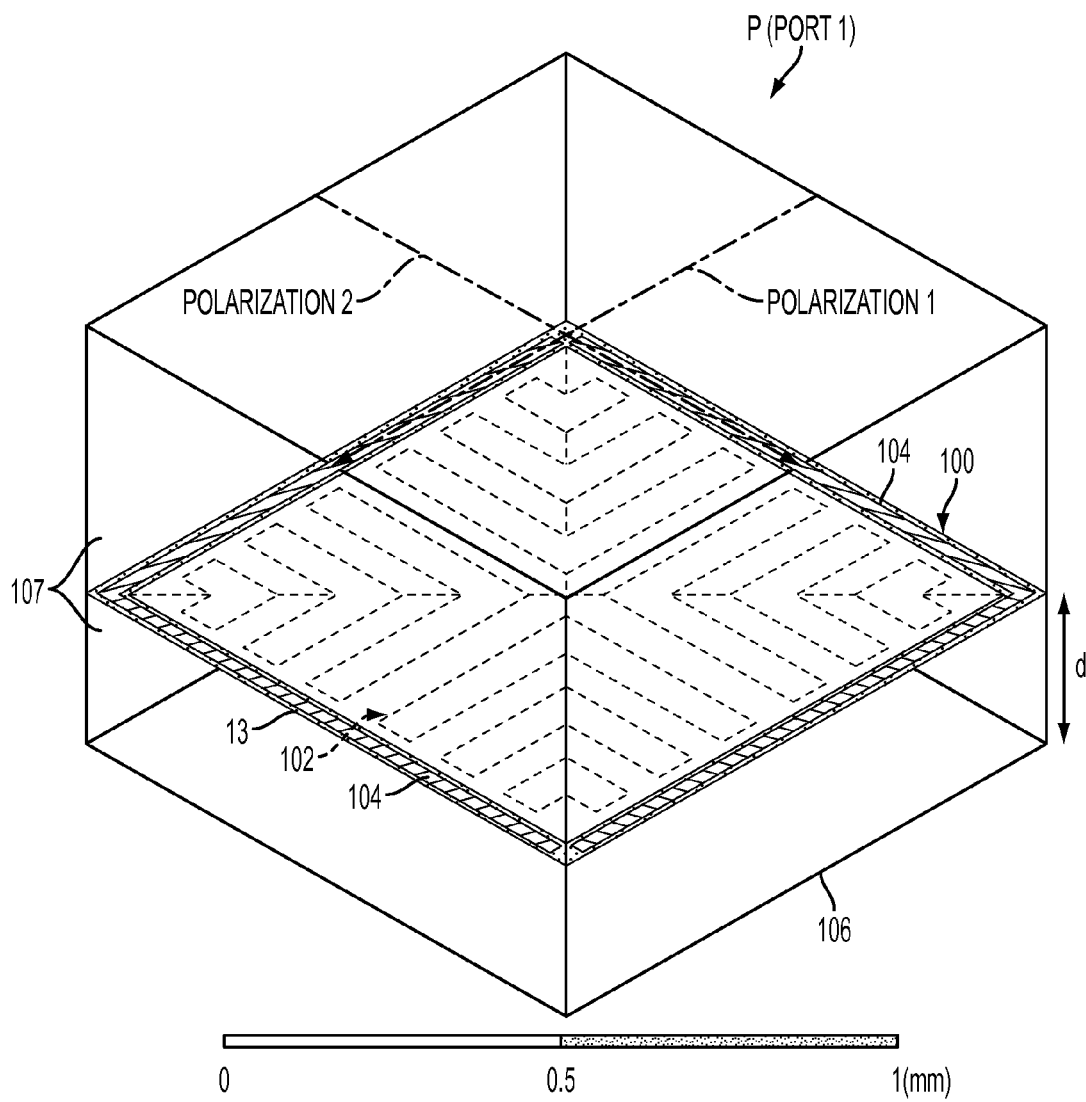


FIG. 5

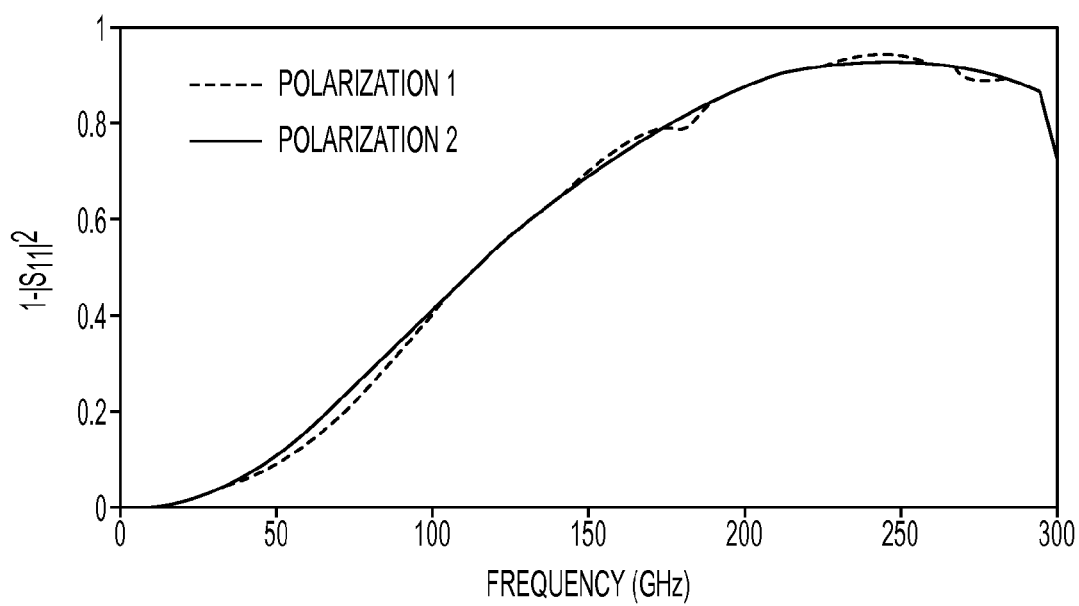


FIG. 6A

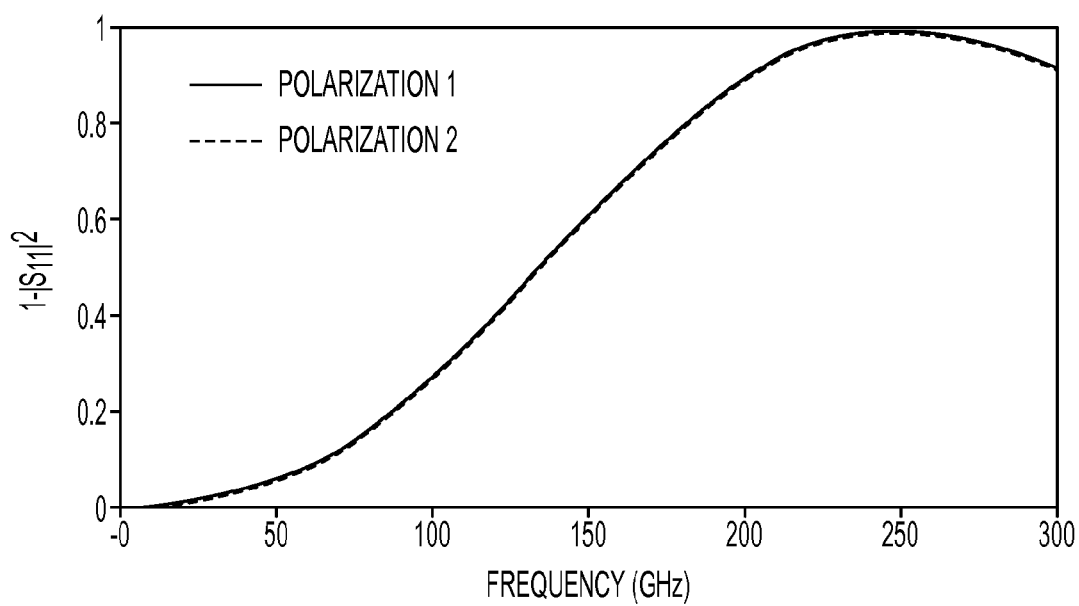


FIG. 6B

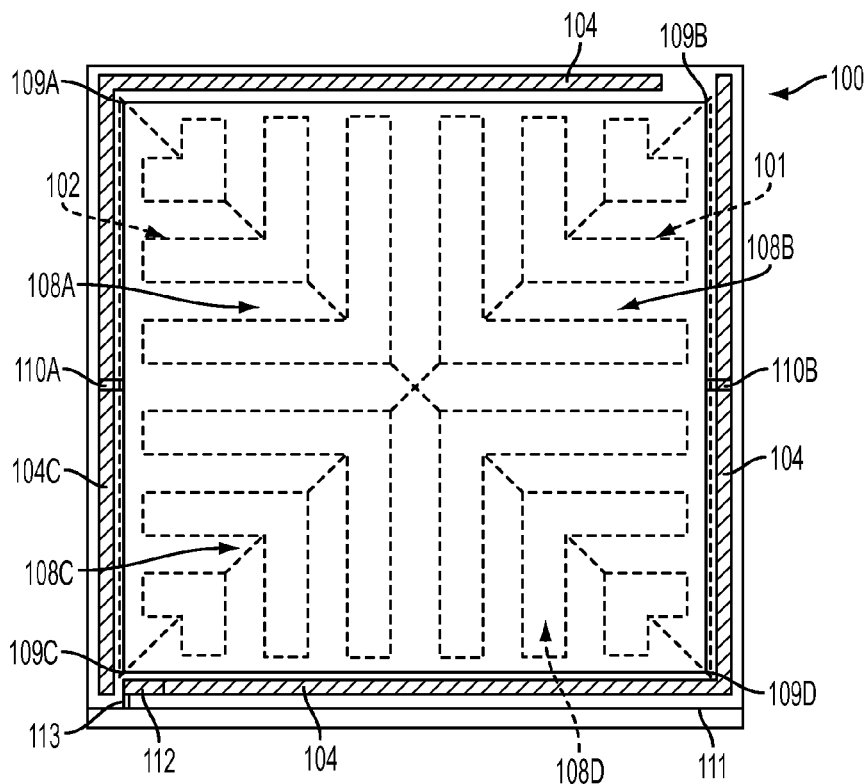


FIG. 7

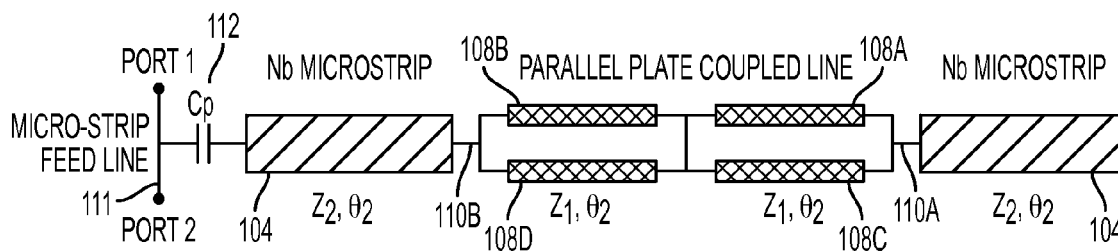


FIG. 8

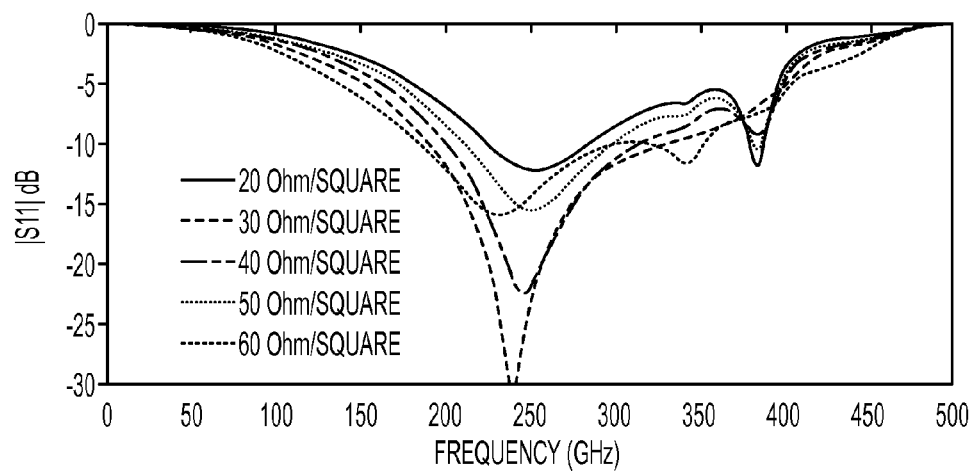


FIG. 9

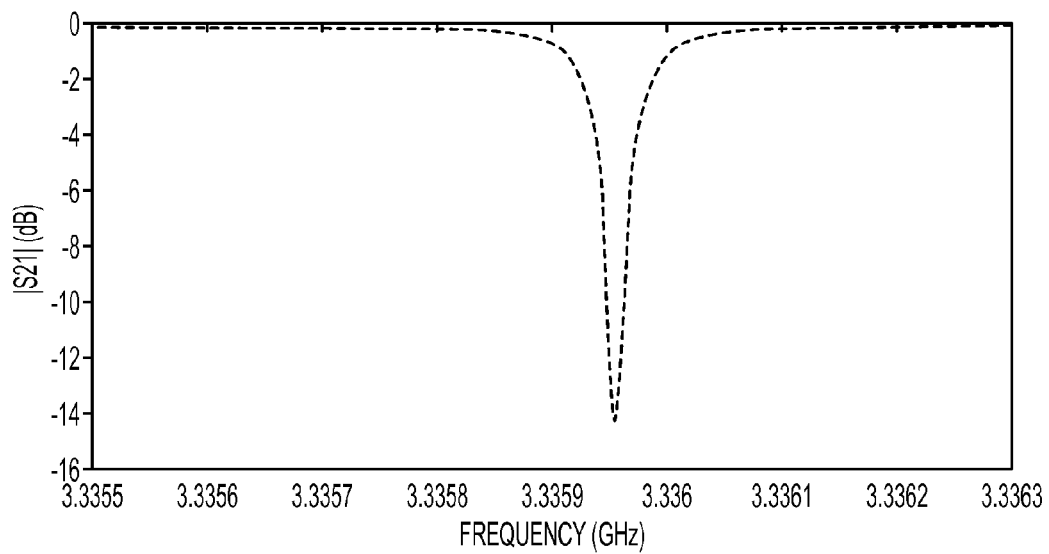


FIG. 10

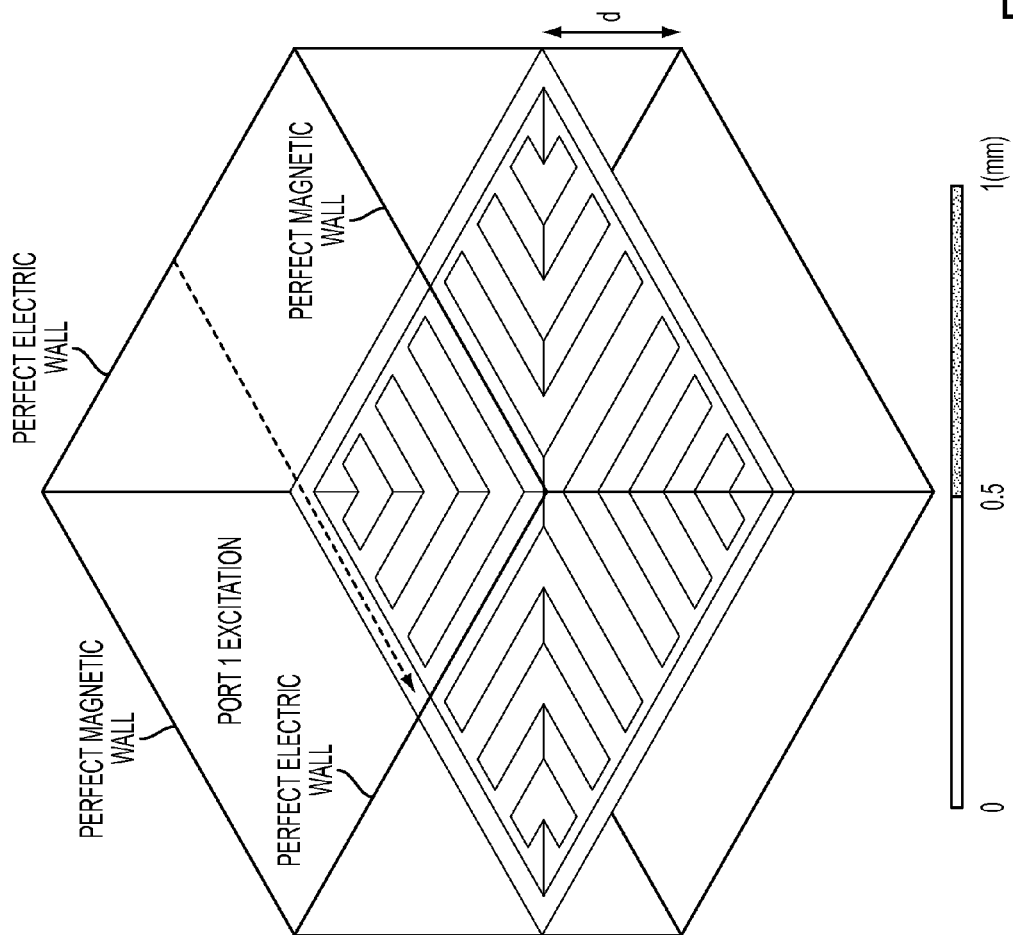


FIG. 11

1

# SYMMETRIC ABSORBER-COUPLED FAR-INFRARED MICROWAVE KINETIC INDUCTANCE DETECTOR

## ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for Government purposes without the payment of any royalties thereon or therefore.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to an absorber-coupled far-infrared microwave kinetic inductance detector (FIR MKID) array with a symmetric cross pattern which serves dual roles as radiation absorber and superconducting readout. The metal pattern on the inductance detector allows power to be more evenly distributed across the detector area than the prior art, thus, increasing the detector coupling efficiency and sensitivity. Furthermore, the cross absorber pattern allows the output of the detector to readout at more than twice the frequency of a conventional MKID design. Finally, the arrangement of the detector's resonator transmission line minimizes parasitic coupling among the adjacent resonator channels. This arrangement reduces the complexity in resonator calculations and allows more detectors to be frequency multiplexed in a limited microwave frequency readout bandwidth with significantly small crosstalk.

### 2. Description of the Related Art

A microwave kinetic inductance detector (MKID) is a superconducting photon detector which operates at cryogenic temperatures, typically below 1 degree Kelvin. The MKID is used in high-sensitivity astronomical detection for frequencies ranging from the far-infrared (FIR) to X-rays. The kinetic inductance of the superconducting transmission line forming the MKID is inversely proportional to the density of the Cooper pairs, and thus, the kinetic inductance increases upon photon absorption. When combined with a capacitor, a microwave resonator is formed, in which its resonant frequency changes with the absorption of photons. The resonator-based readout is useful for developing large-format detector arrays, as each kinetic inductance detector can be addressed by a single microwave tone, and many kinetic inductance detectors can be measured using a single broadband microwave channel (i.e., using frequency-divisional multiplexing).

Single-layer uniform co-planar waveguide or parallel coupled transmission lines are commonly used to generate the FIR MKIDs. A microstrip electrical transmission line provides greater confinement and signal control in this detector readout application. Further, planar transmission line structures are less expensive, lighter, and significantly more compact than traditional waveguide technologies.

A conventional microwave kinetic inductance detector (MKID) **10** (see FIG. 1), to which power  $P$  is applied, includes a meander or a spiral line resonator pattern **11** of an infrared (IR) absorber **12**, disposed on a thin membrane **13** of silicon as a dielectric substrate layer (see FIG. 2 for a cross-sectional view of FIG. 1 along line "A"). The absorber **12** may be made of any superconductor material with a transition temperature lower than niobium, including aluminum, titanium nitride, molybdenum nitride etc.

The microstrip electrical transmission line of the conventional MKID **10** includes a low impedance ( $Z$ ) conducting strip **14** along two edges thereof, separated from a ground plane **15** by the silicon membrane **13**. The conducting strip **14**

2

is a superconductor at FIR frequencies and at microwave frequencies. The microwave component is formed from the microstrip **14** and includes the metal pattern **11** of the FIR absorber **12**, which also serves as a superconducting resonator at the readout microwave frequency (i.e., typically between 0.3 and 10 GHz). The parallel-transmission line **11**, **12** are at an FIR quarter-wave spacing or distance "d" from a conductor backshort **16**.

However, disadvantages of the prior art MKID **10** include: 1) a metal pattern **11** which produces asymmetric power coupling for both horizontal and vertical signals; 2) the uniform transmission line used in the resonator results in a high resonator current confined around the center of the microwave kinetic inductance detector (MKID) **10**, thus, limiting the MKID **10** sensitivity, and potentially producing strong crosstalk to the adjacent MKID channels; 3) strong parasitic coupling among resonators which produce uncertainty in the resonance frequency calculation, thus, limiting the minimum frequency spacing among MKID channels for large detector array implementations; and 4) the metal pattern **11** on the membrane **13** results in low microwave operating frequencies, which limits the maximum number of resonator channels that can be readout by a cryogenic amplifier. Accordingly, an FIR MKID **10** that does not have these disadvantages is desired.

## SUMMARY OF THE INVENTION

In one embodiment, an absorber coupled FIR MKID of the present invention requires a cross absorber metal pattern and sheet resistance to efficiently absorb power at FIR frequencies. In addition, the absorber behaves as a half-wave resonator at microwave frequencies and can be used in frequency-multiplexed detector readout systems.

In one embodiment, a far-infrared microwave kinetic inductance detector includes: a membrane having an absorber disposed thereon; and a microstrip including a plurality of conductor microstrip lines disposed along all edges of the membrane, and separated from a ground plane by the membrane; wherein the absorber is disposed in a pattern, including a symmetric cross bar pattern, on the membrane.

In one embodiment, the pattern is made from a metallic material as the absorber, and the conducting microstrip lines are made from niobium.

In one embodiment, the metallic material of the pattern is formed from a superconducting material with a transition temperature below niobium, including one of aluminum, titanium nitride, or molybdenum nitride.

In one embodiment, the pattern is disposed on both a top and a bottom of the membrane, and creates a parallel-plate coupled transmission line on the membrane that acts as a half-wavelength resonator at readout frequencies.

In one embodiment, the parallel-plate coupled transmission line and the conductor microstrip lines form a stepped impedance resonator.

In one embodiment, the conductor microstrip lines are disposed at a top and at a bottom of the membrane, and the microstrip lines at the bottom of the membrane are at a far infra-red quarter-wave spacing from a conductor backshort.

In one embodiment, a spacing between any two lines of the pattern on the membrane is set at most  $\frac{1}{2}$  of a wavelength at a shortest infra-red wavelength to minimize sheet reactance, provide an effective impedance match to that of free space, and minimize diffractive scattering from the metallic material as absorber.



In one embodiment, the pattern provides identical power absorption for both horizontal and vertical polarization signals.

In one embodiment, the pattern on the membrane is divided into four sections.

In one embodiment, two outputs of two of the four sections combine a respective two of the four sections at two points of the conductor microstrip lines to produce the stepped impedance resonator.

In one embodiment, the stepped impedance resonator is coupled to a microstrip feed line via a parallel-plate capacitor which performs as an impedance inverter.

In one embodiment, the detector is utilized at cryogenic temperatures below the transition temperature of absorber metallization of the superconducting material.

In one embodiment, the pattern increases a resonance frequency of the stepped impedance resonator, to increase a channel capacity of the detector when used in a large array configuration.

In one embodiment, the pattern allows power to be more evenly distributed across a physical area of the detector to increase detector sensitivity.

In one embodiment, the parallel-plate coupled transmission line minimizes parasitic coupling among adjacent resonator channels.

In one embodiment, the detector is frequency multiplexed in a limited microwave frequency readout bandwidth with reduced crosstalk.

In one embodiment, detector is used in space applications to detect very low power far infra-red frequency signals that have both horizontal and vertical polarizations.

In one embodiment, the detector is installed in low background optical systems.

In one embodiment, the detector is used in millimeter to sub-millimeter radiation detection.

Thus, herein are outlined some features consistent with the present invention, in order that the detailed description thereof that follows, may be better understood, and in order that the present contribution to the art, may be better appreciated. There are, of course, additional features consistent with the present invention that will be described below and which will form the subject matter of the claims appended hereto.

In this respect, before explaining at least one embodiment consistent with the present invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. Methods and apparatuses consistent with the present invention are capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein, as well as the abstract included below, are for the purpose of description and should not be regarded as limiting.

As such, those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for the designing of other structures, methods and systems for carrying out the several purposes of the present invention. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the methods and apparatuses consistent with the present invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In order that the advantages of certain embodiments of the invention will be readily understood, a more particular

description of the invention briefly described above will be rendered by reference to specific embodiments that are illustrated in the appended drawings. While it should be understood that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings, in which:

FIG. 1 is a plan view of a conventional spiral pattern microwave kinetic inductance detector (MKID).

FIG. 2 is a cross-sectional view of the conventional microwave kinetic inductance detector (MKID) of FIG. 1.

FIG. 3 is a plan view of a cross absorber patterned far-infrared microwave kinetic inductance detector (FIR MKID), according to one embodiment consistent with the present invention.

FIG. 4 is a cross-sectional view of the far-infrared microwave kinetic inductance detector (FIR MKID) of FIG. 3, according to one embodiment consistent with the present invention.

FIG. 5 is a perspective view of a unit cell of the FIR MKID with cross absorber metal pattern, according to one embodiment consistent with the present invention.

FIG. 6 (a) is a graph showing a simulated FIR power absorbed by the conventional spiral pattern MKID at two different polarizations.

FIG. 6 (b) is a graph showing a simulated FIR power absorbed by the cross pattern FIR MKID at two different polarizations, according to one embodiment consistent with the present invention.

FIG. 7 is a plan view of an implementation of the cross pattern FIR MKID, with MKID resonator response for frequency-multiplex read-out in microwave frequency band, according to one embodiment consistent with the present invention.

FIG. 8 is a schematic view of an equivalent transmission line model of the resonator and its readout interface at microwave frequency, according to one embodiment consistent with the present invention.

FIG. 9 is a graph showing a simulated return loss of the MKID using various FIR absorber sheet resistance values, according to one embodiment consistent with the present invention.

FIG. 10 is a graph showing a simulated FIR MKID response seen by a microstrip feed line, with the resonator having a coupling quality factor of 70,989, according to one embodiment consistent with the present invention.

FIG. 11 is a perspective view of a unit cell with electromagnetic simulation setup of the MKID in an infinite array configuration to simulate the power absorbed by the detector, according to one embodiment consistent with the present invention.

#### DESCRIPTION OF THE INVENTION

The present invention relates to an absorber-coupled, extended far-infrared microwave kinetic inductance detector (FIR MKID) array, with cross absorber pattern, which can couple an FIR signal symmetrically at both horizontal and vertical polarizations. The absorber behaves as a half-wave resonator at microwave frequencies and can be used in frequency-multiplexed detector readout systems. The FIR MKID can be readout at higher operating frequencies than conventional MKID designs, thus, increasing the detector array channel capacity. The present invention also produces low parasitic coupling to the adjacent detector channel to simplify the design and minimize interferences.

5

In one embodiment, the FIR MKID **100** of the present invention, to which power  $P$  is applied (see FIG. **3**), is of a suitable size (i.e., 1.03 mm square), and includes a symmetric cross absorber resonator pattern **101** of infrared (IR) absorber **102**, disposed on a thin (i.e., approximately 5  $\mu\text{m}$ ) membrane **103** of silicon (see FIG. **4** for a cross-sectional view along line “A”).

In one embodiment, the microstrip electrical transmission line of the FIR MKID **100** includes low impedance ( $Z$ ) conducting strips **104** along all four edges thereof, separated from a ground plane **105** by the silicon membrane **103** as a dielectric substrate layer.

The conducting strips **104** along the edges of the membrane **103** are a superconductor at FIR frequencies and at microwave frequency. The microwave component is formed from the microstrip electrical transmission line and includes the metal pattern **101** as an FIR absorber **102**, which is a superconductor at RF. The microstrip line is at an FIR quarter-wave spacing or distance “ $d$ ” from a conductor backshort **106**.

At infrared (IR) frequencies, the MKID’s superconducting metal pattern **101** behaves as an absorber. In one embodiment, the superconducting material used in the readout circuit (i.e., conducting strips **104** on the border of the pixel and microstrip lines running to the readout) is niobium. In one embodiment, the superconducting metal **102** used in the absorber/resonator structure (i.e., material **102** disposed on the dielectric membrane **103** which absorbs photons whose frequency is greater than the superconducting gap frequency, the photo absorption which breaks electron-electron or Cooper pairs and results in a shift in the resonant frequency), is a material **102** with a transition temperature below niobium, including one of aluminum, titanium nitride, or molybdenum nitride.

In one embodiment, the metal pattern **101** of the FIR MKID **100** for FIR absorption includes a symmetric cross bar pattern **101** on the membrane **103** which is used to provide identical power absorption for both horizontal and vertical polarization signals (see FIG. **5** for polarizations **1** and **2**, for a unit cell of the FIR MKID **100** in a vacuum **107**). The FIR power  $P$  absorbed by the metallic cross bar pattern **101** is different from that of the simulated spiral pattern **11** of the conventional MKID **10** (see FIG. **1**) at the two different polarizations, as shown in FIGS. **6A-6B**. In the graphs shown in FIGS. **6A-6B**, the metallization sheet impedance is 40 Ohm/square, however, this may be changed appropriately, since the pixel’s total filling fraction is adjusted to realize an appropriate impedance to maximize FIR coupling. Two absorber configurations are commonly used in practice: 1)  $Z_o(\text{FIR})$  equal to the impedance of freespace ( $\eta = 377$  ohm/square) followed by a termination with quarter wave resonant backshort to achieve near unity coupling over a ~30% fractional waveband and 2)  $Z_o(\text{FIR}) = \eta / (\sqrt{\epsilon_r(\text{substrate})} - 1) = 157$  ohms/square followed by a matched termination to approximate a frequency independent response in the presence of the absorbers supporting substrate membrane (i.e., in this case the dielectric constant  $\epsilon_r(\text{substrate})$  is 11.7 for silicon).

In considering the FIR coupling the several elements of the pixel geometry used in the array come into consideration in optimization of the coupling: 1) the fraction of the area presented by the absorber should be dominated over that required by the readout, 2) in realizing  $Z_o(\text{FIR})$  the spacing between lines should be  $< \lambda_{\min}/5$  to minimize diffractive losses, and 3) the pixels in the array should be  $> \lambda_{\max}/2$  to maximize coupling of the detector to the incident radiation. Here  $\lambda_{\min}$  and  $\lambda_{\max}$  are the shortest and longest wavelengths of interest in the FIR signal band,” or similar.

6

In one embodiment, the cross bar metal pattern **101** of the absorber **102** is placed on both the top and bottom of the membrane **103** (see FIG. **4**) to create a parallel plate coupled transmission line that acts as a half-wavelength resonator at readout frequencies. More specifically, in one embodiment as shown in FIG. **7**, the parallel-plate transmission line on the membrane **103** is split into four sections **108A-D** in a symmetric cross bar pattern **101**. Although the metal pattern **101** is shown as symmetrical in FIG. **7**, one of ordinary skill in the art would know that the arrangement may be of any design as long as it provides the current density required to keep the resonator frequency high. In the embodiment, the spacing between any two lines of the metal pattern **101** on the membrane **103** is set at most  $1/5$  of a wavelength at a shortest infra-red wavelength to minimize sheet reactance, provide an effective impedance match to that of free space, and minimize diffractive scattering from the absorber **102**.

In one embodiment, at microwave frequency, the parallel-plate transmission line in the membrane **103** area is connected to the low impedance ( $Z$ ) microstrip line **104** at the FIR MKID **100** edges, to form a stepped impedance resonator. More specifically, in one embodiment, two outputs (i.e., **109A** and **109C**, or **109B** and **109D**) from two sections (i.e., **108A** and **108C**, or **108B** and **108D**, respectively) of the parallel plate transmission line of the FIR MKID **100** combine the two sections (i.e., **108A** and **108C**, or **108B** and **108D**) at points **110A** or **110B**, respectively, of the microstrip line **104**, to produce the stepped impedance resonator (see FIGS. **7-8**). The impedance contrast in the parallel-coupled line ( $Z_1$ ) of the four sections **108A-108D**, and the conducting microstrip lines **104** ( $Z_2$ ), forces most of the current to be on the membrane **103** (see FIG. **8**). This produces high variation in kinetic impedance of the metal absorber **102** on the membrane **103** area, thus, increasing the FIR MKID **100** sensitivity. The resonator is coupled to a microstrip feed line **111** via a parallel-plate capacitor **112**, at connection **113**, on one side of the resonator (see FIG. **7**). The capacitor **112** behaves as an impedance inverter. At resonance frequency, the resonator behaves as an electrical short at the feed line **111**. As a result, signal transmission in the feed line **111** is reflected at resonance frequency.

In one embodiment, the metal pattern **101** of the FIR MKID **100** is designed to have the effective area match with the characteristic impedance of that in free space, resulting in minimum return loss at the center of the operating frequency (see FIG. **9** which shows a simulated return loss of the MKID **100** using various FIR absorber sheet resistant values). This maximizes the power absorption in the metal pattern **101** causing the temperature of the metal absorber **102** to increase. At RF, this metal pattern **101** becomes a superconductor with the kinetic inductance changes dependent on the temperature of the metal **102**. The detector **100** is operated at cryogenic temperatures below the superconducting transition temperature of the absorber metallization.

In one embodiment, FIG. **10** shows a graph of a simulated FIR MKID **100** response seen by a microstrip feed line **111**. The resonator has a quality factor of 70,989 in this simulation.

In one embodiment, when connected to a low impedance transmission line **104** at both ends **110A**, **110B** along the membrane **103** edges of the FIR MKID **100** (see FIG. **7**), the FIR MKID **100** behaves as a half-wave resonator with its resonance frequency sensitive to IR incident power  $P$  (see FIG. **5**). The impedance contrast between two types of transmission lines **104** causes the electrical current to be concentrated in the membrane **103** area. This keeps the majority of heat within the membrane **103** area, thus, increasing the sensitivity of the FIR MKID **100**.

In one embodiment, the four sections **108A-108D** of the transmission lines combined in parallel allow a long transmission line to exist in the membrane **103** area without increasing the electrical length of the resonator. Therefore, the FIR MKID **100** can produce a resonance frequency of at least 200% higher than any conventional half-wavelength FIR MKID.

In one embodiment, for an FIR MKID **100** made of aluminum superconductor material, operating at about 0.3 K, the total noise equivalent power is determined to be  $1.1 \times 10^{-16}$  W/sqrt (Hz). The FIR MKID **100** is designed to receive IR power of 10 pW at the frequency ranges between 230 and 270 GHz.

In one embodiment, the FIR MKID **100** requires a cryogenic cooling system with two RF interconnections on the FIR MKID **100**. An RF signal generator is used to inject RF power into the RF feed line **111**. In one embodiment, the silicon substrate **103** (at cryogenic temperatures) is virtually invisible to the incident far-IR (FIR) radiation, and absorption takes place in the resonator metallization (i.e., metal pattern **101**), and in effect, the resonator plays the role of absorber **102** and a means of readout.

In one embodiment, a vector network analyzer or an in-phase/quadrature-phase mixer and amplifier are required to readout the signals. Since the RIF MKID **100** contains the membrane **103**, it requires careful handling. Due to its operation in a vacuum environment, pressure in the FIR MKID **100** system must be carefully monitored to assure slow increase or decrease in pressure to prevent any membrane **103** damage. In one embodiment, the FIR MKID **100** is kept in a nitrogen box for storage and to prevent exposure to normal air to reduce the chance of oxidation of the detector material **102**.

In one embodiment, the superconductor material **102** can be changed to further increase the detector channel capacity and sensitivity of the FIR MKID **100**.

In one embodiment, the FIR MKID **100** has been modeled in an electromagnetic simulation software (see FIG. 11 showing an electromagnetic setup of the FIR MKID **100** in an infinite array configuration to simulate the power P absorbed by the detector). In one embodiment, the resonance frequency of the resonator of the present invention matched with what was obtained from the electromagnetic simulation within a few percent.

Thus, in summary, the FIR MKID **100** of the present invention includes features of a symmetric cross-shaped, meandered, transmission line pattern **101** that allows the IR signal to be coupled to the metal absorber **102** equally for both horizontal and vertical polarization. This pattern **101** also increases the resonance frequency of the resonator, thus, increasing the channel capacity of the FIR MKID **100** when used in a large array configuration. A parallel coupled transmission line has strong field confinement between two conductors **104**. As a result, the resonator has much weaker coupling field to the adjacent pixels. This reduces the uncertainty in resonance frequency calculation and frequency allocation of each detector.

Further, the FIR MKID **100** of the present invention allows higher absorber **102** filling fraction (at the readout wavelength without blocking the far-IR signal), minimal diffractive effects (a larger single-mode operating bandwidth), higher quantum efficiency (by concentration of the resonator fields in the center of the pixel), while allowing flexibility in tailoring the microwave readout frequency.

Still further, the FIR MKID **100** of the present invention allows incident power to be absorbed equally for both horizontal and vertical polarization. In addition, the new absorber metallization pattern **101** allows power to be more evenly

distributed across the detector area than the conventional detectors, thus, increasing the detector sensitivity. Furthermore, the new pattern **101** allows the output of the detector to be frequency multiplexed at more than twice the frequency of the conventional MKID **10** design. Finally, its resonator transmission line design minimizes parasitic coupling among the adjacent resonator channels. The present invention reduces the complexity in resonator calculations and allows more detectors to be frequency multiplexed in a limited RF readout bandwidth with significantly smaller crosstalk. Ultimately the present invention can reduce energy expenditures and increase data acquisition in space applications.

In one embodiment, the FIR MKID **100** of the present invention is used in space applications to detect very low power far infra-red (FIR) frequency signals that have both horizontal and vertical polarizations, and can potentially be installed in low background optical systems (e.g., ground, balloon, and spaceborne telescopes). In one application of the present invention, the FIR MKID **100** is used in millimeter to sub-millimeter radiation detection (100-700 GHz range). The array technology of the present invention provides a large number of background limited detectors whose RF readout approach reduces the heat load and cooling capacity.

Additional applications of the present invention include space-borne and ground-based imaging, precision metrology, and non-destructive testing (e.g., identification of imperfections in metalloid and non-metal materials). The present invention may also be utilized in a variety of industrial applications, as well as for homeland security screening applications. The FIR MKID **100** of the present invention may be fixed in nature due to the cooling requirements for the technology (i.e., operational at <4 K with the materials consistent with one embodiment of the present invention).

Further, the present invention includes advantages over existing far infra-red (FIR) sensing mechanisms for space and satellite operations. Specific advantages over existing systems include: 1) decreased energy requirements for operation; 2) the ability to operate at very low temperatures (near absolute zero) and, 3) the ability to sense IR signals in the Far IR spectrum.

It should be noted that reference throughout this specification to features, advantages, or similar language does not imply that all of the features and advantages that may be realized with the present invention should be or are in any single embodiment of the invention. Rather, language referring to the features and advantages is understood to mean that a specific feature, advantage, or characteristic described in connection with an embodiment is included in at least one embodiment of the present invention. Thus, discussion of the features and advantages, and similar language, throughout this specification may, but do not necessarily, refer to the same embodiment.

Furthermore, the described features, advantages, and characteristics of the invention may be combined in any suitable manner in one or more embodiments. One skilled in the relevant art will recognize that the invention can be practiced without one or more of the specific features or advantages of a particular embodiment. In other instances, additional features and advantages may be recognized in certain embodiments that may not be present in all embodiments of the invention.

One having ordinary skill in the art will readily understand that the invention as discussed above may be practiced with steps in a different order, and/or with hardware elements in configurations which are different than those which are disclosed. Therefore, although the invention has been described based upon these preferred embodiments, it would be appar-

9

ent to those of skill in the art that certain modifications, variations, and alternative constructions would be apparent, while remaining within the spirit and scope of the invention. In order to determine the metes and bounds of the invention, therefore, reference should be made to the appended claims.

What is claimed is:

1. A far-infrared microwave kinetic inductance detector comprising:

a membrane having an absorber disposed thereon; and  
a microstrip including a plurality of conductor microstrip lines disposed along all edges of said membrane, and separated from a ground plane by said membrane;

wherein said absorber is disposed in a pattern, including a symmetric cross bar pattern, on said membrane, and also wherein said pattern is made from a metallic material formed from a superconducting material with a transition temperature below niobium, including one of aluminum, titanium nitride, or molybdenum nitride, and said conducting microstrip lines are made from niobium and said pattern is disposed on both a top and a bottom of said membrane, and creates a parallel-plate coupled transmission line on said membrane that acts as a half-wavelength resonator at readout frequencies.

2. The detector of claim 1, wherein said parallel-plate coupled transmission line and said conductor microstrip lines form a stepped impedance resonator.

3. The detector of claim 2, wherein said pattern on said membrane is divided into four sections.

4. The detector of claim 3, wherein two outputs of two of said four sections combine a respective two of said four sections at two points of said conductor microstrip lines to produce said stepped impedance resonator.

5. The detector of claim 4, wherein said stepped impedance resonator is coupled to a microstrip feed line via a parallel-plate capacitor which performs as an impedance inverter.

6. The detector of claim 5, wherein the detector is utilized at cryogenic temperatures below said transition temperature of absorber metallization of said superconducting material.

10

7. The detector of claim 5, wherein said pattern increases a resonance frequency of said stepped impedance resonator, to increase a channel capacity of the detector when used in a large array configuration.

8. The detector of claim 7, wherein said pattern allows power to be more evenly distributed across a physical area of the detector to increase detector sensitivity.

9. The detector of claim 8, wherein said parallel-plate coupled transmission line minimizes parasitic coupling among adjacent resonator channels.

10. The detector of claim 9, wherein the detector is frequency multiplexed in a limited microwave frequency readout bandwidth with reduced crosstalk.

11. The detector of claim 1, wherein said conductor microstrip lines are disposed at a top and at a bottom of said membrane, and said microstrip lines at said bottom of said membrane are at a far infra-red quarter-wave spacing from a conductor backshort.

12. The detector of claim 11, wherein a spacing between any two lines of said pattern on said membrane is set at most  $\frac{1}{5}$  of a wavelength at a shortest infra-red wavelength to minimize sheet reactance, provide an effective impedance match to that of free space, and minimize diffractive scattering from said metallic material as said absorber.

13. The detector of claim 1, wherein said pattern provides identical power absorption for both horizontal and vertical polarization signals.

14. The detector of claim 1, wherein the detector is used in space applications to detect very low power far infra-red frequency signals that have both horizontal and vertical polarizations.

15. The detector of claim 14, wherein the detector is installed in low background optical systems.

16. The detector of claim 14, wherein the detector is used in millimeter to sub-millimeter radiation detection in a 30-3000 GHz range.

\* \* \* \* \*